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# Ten Ways to Fool the Masses When Presenting Battery Research\*\*

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As scientists within the field of battery research we may often find it quite difficult to match and trust the promises given in press releases and high-profile papers. Even though there are real breakthroughs, where the results indeed are as impressive as they are marketed to be, we may as often find the reporting of “revolutionary” results to omit critical aspects of the methods and materials used. The absolute majority of researchers do not actively pursue to present their science in any untrue fashion, but poor (ethical) judgement could affect anyone working long hours in a gloomy lab at dusk and at the same time feel being

pressed for publications and citations. Here, we outline ten ways to make your results appear more attractive and groundbreaking than they actually are, especially to laypeople that might not appreciate the full range of difficulties associated with battery research. Consider it a light-hearted entry with respect to scientific quality in methodology and dissemination, that might assist you in looking for nebulous reporting practices in your own and your peers’ work, but please do not consider it a guide, but a humorous contrast to the real publishing guidelines recently launched.<sup>[2–4]</sup>

## 1. Always compare your results against the state-of-the-art from 2010

Everyone knows that nothing has really happened in the field of batteries since 2010. After all, we are still using lithium-ion batteries and they were launched already in the 1990’s, right? And this really helps when your results are not as fancy as those you just read in that high-impact journal paper. Who trusts papers in such journals anyway? While some people might claim that the field really has moved on since you did your very first literature study a decade or two ago, who has the time to update their literature when busy writing yet another paper? You might anyway just be targeting to improve on the understanding of a mechanism discussed the first time in an obscure paper from 1986 and thus all literature since then is not really relevant. If anyway needed, reviewers can be such

a pain, you can for sure always find a bunch of papers that claim that the state-of-the-art today is more or less that of 2010 – so why not cite those? Then you will be totally fine as you in fact are comparing your results to what someone else just published, thus no one can call you out on using out of date references, and the extra benefit is that you continue a great tradition.

## 2. Use only chemical reactions for the energy density

It is so cumbersome to try to figure out what a plausible specific energy density is – so why not just use the chemical reactions? And when you do that, for example, for Li–air or Li–S batteries the performance numbers you can get are just awesome – so much better than those for the Li-ion batteries on the market. Some may claim this to be an unfair comparison, but who said life (or science) is fair? Let’s face it, no one anyway knows how much (or little) active material you can squeeze into the electrodes, and even less you or they should need to think of practical non-active, weight-adding things like electrolyte, separator, current collectors, or even the casing. And, oh yes, of uttermost importance, you never really should describe at what level your data belongs – let the laypeople think that your coin-cell data, in whatever way you arrived at them, is what they one day will get from their EV battery. If you are even considering reporting volumetric energy density (why bother?) and it looks really problematic, your argument can always be that for large-scale grid-storage there will be infinite space anyway.

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[\*\*] Heavily inspired by and a homage to Ref. [1]. Editorial note: This Editorial article is written in a humorous tone and has been peer reviewed. It should not be taken as literal advice by the scientific community.

### 3. Quote cost only in terms of the raw materials used

Absolutely do not confuse your readers with any possible or even likely worrisome problems of actual production and business. There is no need at all to point out that your awesomely performing coin-cells (well, face it, in the end you only had material enough to make a single one that worked), having electrodes designed as “interlaced 3D nanowires painting the picture of a basket of mixed fruit”, were made using an active material obtained in synthesis of 8 steps at 1200 °C and 2 weeks for a few mg in 2% yield. Hey, it's science, it is supposed to be hard! Rather quote that the starting materials, using the prices of kilo-sized batches from Sigma-Aldrich, are so inexpensive that nothing stops anyone from doing your highly novel electrodes almost for free. As it happens, you have patented the synthesis route, so there might though be some additional costs. Finally, if any of the metals you used are abundant, then by no means forget to mention this, even if your active material in the end only has 1 wt% of those metals and your electrode of course even less.

### 4. Carefully choose your cycling conditions

There are so many options when choosing the cycling conditions of your cells – here you can really show that you know what you are doing. If you have problems of self-discharge and/or parasitic side-reactions at the electrolyte/electrode interfaces/-phases, then do use high C-rates and a little bit narrower state-of-charge (SoC) ranges. Everyone loves to hear about cells enabling fast-charging and if you (quietly) combine this with the energy density for the full SoC window (why not?) you all of a sudden have a cell showing both high energy and high power – awesome! In the end, it is anyway up to battery pack designers and engineers to tune the SoC windows for the final application – you cannot do everything! On the other hand, if your electrolyte has “some remaining problems” of sufficient ion transport from mass transfer limitations, then be sure to run the cells at C/20 or slower with the aim to “really show the impressive fundamental energy density reachable”. After all, all you have to do, in the future – by no means now and here – is to simply make the electrolyte work a little better and this is not at all that difficult, anyone who claims so is simply not at your level. They have likely never even raised the temperature to get higher ion conductivities, or “mixed up” the solvent mass and solvent volume, or “forgot” to check the dryness of the electrolyte – and it is always up to the commercial provider to ensure a low water content.

### 5. Quietly change the procedure, layout or materials composition

Even if much can be done by choosing the test protocol wisely, you can reach much further to the perfect presenta-

tion of your fantastic science within the same study by quietly make some small changes in the experimental set-up. A rate and concentration difference here, a loading difference there. Nothing worth mentioning. You can even use another electrolyte in some cells, it doesn't really matter. Never fall into the trap of providing this in a detailed experimental section, place some of the key procedures in the supporting information or as small footnotes to the lengthy tables of data you provide therein (yes, the ones that no one really reads anyway). If someone really tries to reproduce in detail your experiments and even question your results (how dare they!) you are always safe; by not providing some small crucial things you can *always* claim that they do not have *exactly* the same conditions as you and that's simply why their results are totally the opposite of yours.

### 6. Play the game of loadings and ratios

You are focusing on the science, not the technology. That's a hill to die on! This can, for example, prevent you from being occupied by irrelevant problems of technologically relevant active material loadings and electrolyte volumes. Not only that, but it can also be used to improve the capacity of your cells in several ways. Who says no to some additional capacity?! The simplest trick is to use very thin electrodes made with high % of conductive carbon additives, you can then quote high capacity per active material (see 2 above), you get less (catalytic) electrolyte degradation and rid of many mass transport limitations. Additional good things happen when you use high electrolyte to active material ratios. You can almost always achieve longer cycling (the cell does not dry out) and for battery chemistries such as Li-S batteries, you can even alter the reaction pathways and avoid those unnecessary solubility limitations (that no one wants anyway). It is obviously very important to not mention the electrolyte volume nor the final content of active material in the cell – so that no one can calculate the actual charge transferred during a cycle. These data must be considered as only a very practical aspect and thus only relevant for commercialization, not to be bothered with at this stage. Scientific freedom must include freedom to build the cells you want!

### 7. Never do proper characterisation of your (promising) materials

The easy way out here is to just show some overall X-ray diffraction patterns or Raman spectra, never mind some minor impurities or details such as the risk of bulk/surface differences. Also, do that only for the as-synthesized material and not after any treatments such as ball-milling. Then, get some nice cycling and capacity for the first few cycles and report. Do not do any more characterisation of your new active material during/after cycling – what can possibly happen? And that thing with *operando* studies is only a silly

trend and also very cumbersome experiments to do. The same is true for applying a lot of different characterisation techniques to the very same material – what a waste of time, as anyway one knows how the material works from its very design. On the other hand, if you really have run out of ideas for new materials or concepts, choose only the most exotic characterisation technique you possibly can get hold of, study some phenomenon no one has bothered about yet (do not wonder why that is the case), and present this as a “most unique” (you surely know better buzz words) study revealing “highly important” information. Then you should be all set for publication in any high-impact journal. That the single experiment cost \$100,000 is only a bonus, as it more than anything reveals its importance. Additionally, you have a very good excuse for not having more than a single, sometimes rather crappy, data set, that anyhow took you months to analyse and was collected from a very special designed and electrochemically far from optimal *operando* cell, sometimes assembled outside the glove-box. This is all very much needed and useful if anyone would dare question the very special conclusions you reached. After all, perhaps it would have been better to run a few extra cells with a less fancy method, but that’s no fun. But, really, the ultimate way to avoid all problems associated with characterisation is to simply ignore it altogether; grab your newly made materials, active materials as well as electrolytes, create a few cells, run them, and report as much electrochemical data you can get hold on.

### 8. Anything can be solid-state, right?

You really have to take part in (all) the trends within the community; remember when you were doing nothing else but Li–air batteries? Everyone that mattered was doing it. Now it is solid-state batteries (SSBs). That the science of SSBs and especially their electrolytes, the SSEs (yes, they love acronyms), can be difficult is absolutely no excuse for you to not be world-leading and excellent right from the start. But why do the electrolyte people have to give so much attention to details? If you find an SSE with unprecedented ion conductivity this surely arises entirely from your material and not from remaining solvent, never ever check for this, or the experimental set-up. And never mind electrochemical stability or other practical properties. Also, why are people so rigid; adding a bit of plasticizer or solvent does help a lot and the material is still (almost) a solid, right? If questioned, you can always resort to use the prefixes “quasi”, “semi” or, worst-case scenario, “hybrid”. However, never use “all” – the old boys club of ASSBs may react violently.

### 9. Errors? – not here

No one does it, no one likes to talk about it, so why should you? There are so very many valid excuses to not have to bother about reproducibility and statistics; expensive materi-

als, long synthesis routes, long and costly cycling, etc. Your three-month long cycling of the single coin-cell that actually made it past the first two days surely is valid data and reproducible, no need to redo *that* one. What were you even thinking of when you made five cells of the same kind? Or when you measured several times the ion conductivity to get some error bars? No, inclusion of statistical measures and error analysis is not really needed in battery science, we instead (mis)trust each other. If we adhere to the view that deviation is “a feature not a bug” this also opens for so many more papers to be published. But the data that were far from what you expected, *those* must for sure be remeasured. There are indeed some errors you cannot really avoid, such as the variation in Coulombic efficiency during cell cycling. But do not fear, it doesn’t mean you really have to show it; we have all heard that the y-axis should cover 0–100%, right? Then no one will be able to spot how the CE varies erratically and sometimes is above 100%. You should also use very thick graph lines, as no one wants to zoom-in on every figure, this is especially useful for not so well refined X-ray diffraction patterns, choppy cyclic voltammograms, and bad EIS fits. With respect to the latter, the selection of the equivalent circuit for the EIS analysis out of the many possible must never be motivated nor the errors commented.

### 10. If all else fails, show pretty pictures and videos

Let’s face it: sometimes your results are, despite following all the advice given above, not as revolutionary as expected and you might mistrust. But every scientist knows that people love colour graphics, fancy micrographs, and tomography images. Do not worry about the relevance of those exact techniques to the purpose or the point of your study, you can always make any claim you want, and displaying cool data can never be wrong. As a plus these often make for great table of content graphics, and as we all know this is how our colleagues choose what papers to read. And speaking of graphics; *every* paper does need a pretty “rocking-chair” schematic, as people might have forgotten the working principle. Repetition is the mother of all learning! With the ever increasing presence of various web channels and social media, both at your own university and within journals and publishing houses, all more than willing to promote your science, there really is no excuse to not try to make the very most of the very tiniest. Thus: if all the above fails, make a nice animation or video!

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